Shear banding formation in vicinity of micro-patterned surfaces

Diana Broboana, Nicoleta Octavia Tanase, Corneliu Balan
REOROM Laboratory, Hydraulics Department, University Politehnica of Bucharest
Splaiul Independentei 313, 010121 Bucharest, Romania
corneliu.balan@upb.ro

1. Introduction:

Complex fluids included in the category of soft matter are subject to material instability which generates in particular configurations the shear banding phenomena, i.e. coexisting under the same shear stress of layers which are flowing at different shear rates, [1-2]. Initially a homogeneous sample, when the yield state is reached the material discloses a phase separation within the flow domain.

The shear banding formation in micro-geometries, especially in the presence of micro-patterned surfaces, is of interest for many applications involving the characterization, transport, separation and flow control of complex liquids, [3]. The present paper is concerned with the numerical study of the shear banding formation in a rotational plate-plate geometry, in the vicinity of a patterned surface with micro-cylindrical pillars. The goal of the work is to detect the shear banding formation on the micro-pillars and to analyze the influence of phenomena on the drag force and friction torque.

2. Numerical results and discussions:

Simulations are performed with the Fluent code, which solves the Cauchy equation for a generalized Newtonian fluid, where the extra-stress ($\mathbf{T}_\mathrm{E}$) – stretching ($\mathbf{D}$) relation is given by,

$$\mathbf{T}_\mathrm{E} = 2\eta(\dot{\gamma})\mathbf{D}, \text{with } \frac{\eta(\dot{\gamma}) - \eta_\infty}{\eta_0 - \eta_\infty} = [1 + (\lambda\dot{\gamma})^2]^{\frac{n-1}{2}}. \quad (1)$$

In (1) $\dot{\gamma}$ is the local strain rate, $\eta(\dot{\gamma})$ is the Carreau viscosity function with $\eta_0 = 1\ Pas,\ \eta_\infty = 1\ mPas, \lambda = 1\ s$ and $n \in [-1, 1]$. For negative n-index the corresponding flow curve is non-monotonous, so the model is unstable and has the potential to generate shear banding, [1], [3].

The working geometry is a symmetric parallel plate – plate configuration with the radius $R = 12.5\ mm$ (lower plate at rest and the upper plate rotated with constant angular velocity ω). The flow domain is divided in 8 bands (equidistant from the center of the discs) and 24 sectors of 15$^{\mathrm{o}}$ each, the nominal gap between the plates being of $300\ \mu m$. The upper plate is smooth; on the lower plate are constructed cylindrical pillars (pins) with the aspect ratio of 1 ($d = h = 100\ \mu m$; 9 pillars on the intersection between the band and the sector, 1512 pillars in total), Fig. 1.

The results of the simulations are shown in Figs. 2 and 3. The shear banding formation is observed on the pillars surface if the local wall shear stress (WSS) reaches the yielding value, see Fig. 3c.

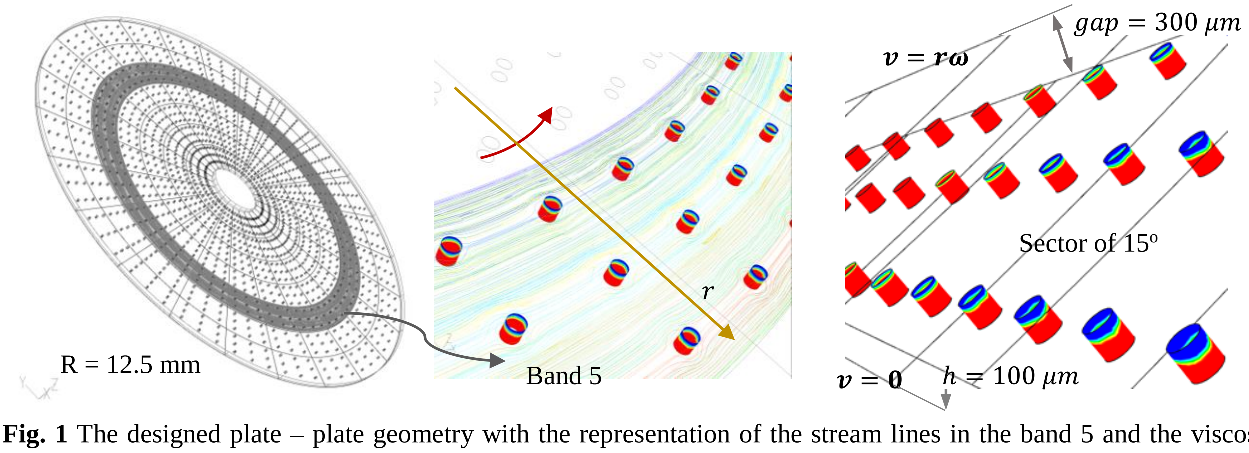

Fig. 1 The designed plate – plate geometry with the representation of the stream lines in the band 5 and the viscosity values on the pillars in one of the sectors, see also Fig. 2.

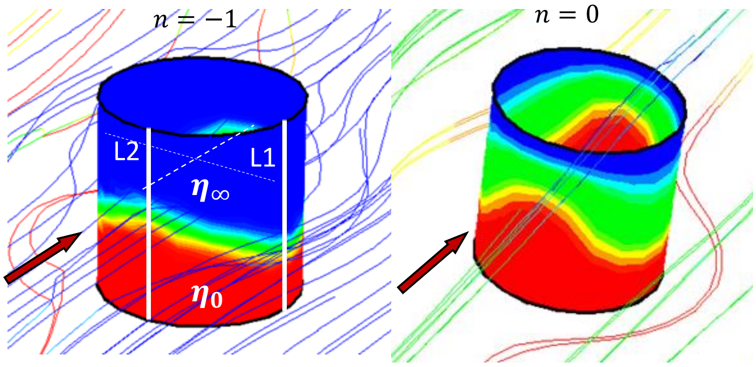

Fig. 2 Viscosity distributions on the surface of the pillar for two Carreau models ($n = -1$ and $n = 0$).
On the pillars are marked the lines L1 and L2; the flow spectrums around the pillars are also represented.
The shear banding formation on the cylindrical surface of the pillar is observed for $n = -1$ (the unstable constitutive relation with non-monotonic flow curve, see Fig. 3c).

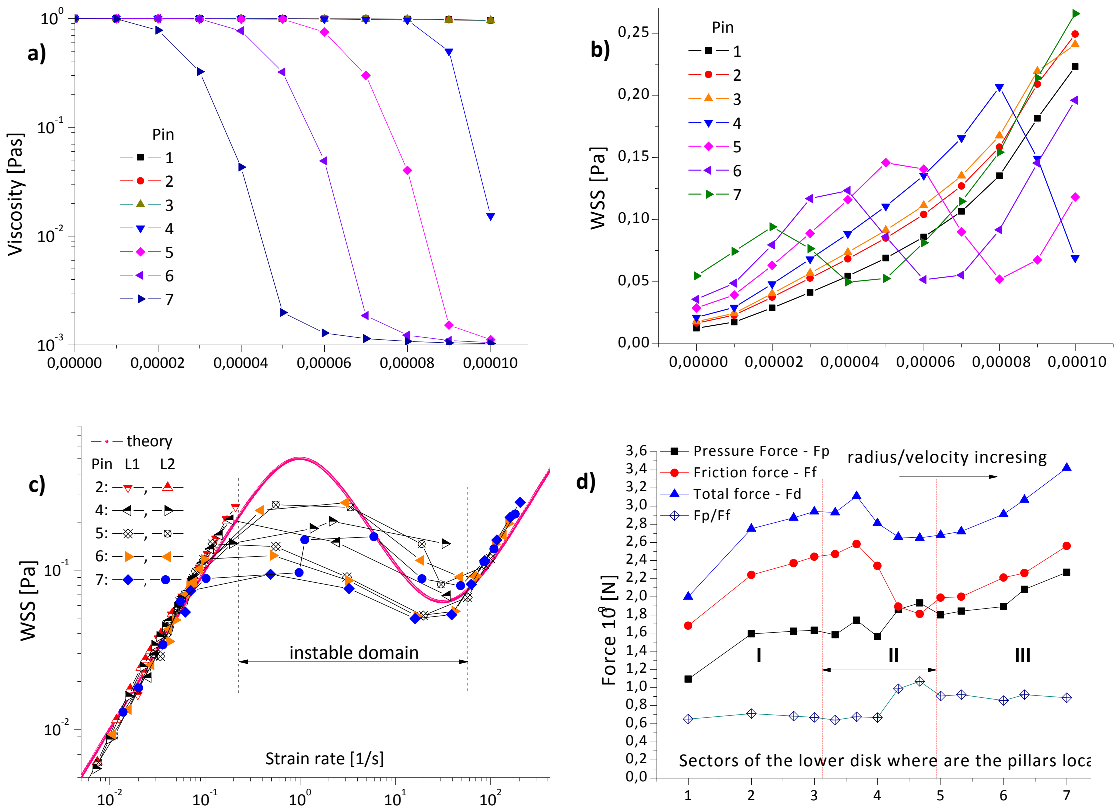

Fig. 3 Numerical computations of the viscosity (a) and WSS (b) on the line L1 of the central pins located in the middle of the bands 1 to 7 (Carreau model *n* = -1). The numerical reconstruction of the flow curve (c) follows the theoretical non-monotonic behavior (1), see also (b), and discloses the domain of instability. The calculated drag force components on the central pins (d): regions I and III are stable, the region II corresponds to the instable domain of the flow curve (c).

3. Conclusions:

The numerical results confirm the shear banding existence on the pillars and the region of instability in vicinity of patterned surfaces for models with non-monotonic flow curve. The process of layers deposition on micro-pillars will be in our furthers studies related with the diffusion at the pillars surfaces and the extraction of components from the transported complex liquids.

Acknowledgements:

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